January 30, 2012

North Carolina Department of Transportation (NCDOT)

Method of Test for

Repetitive Static Plate Load Test of Soils

Modified AASHTO T-221-90 (2008)

1. SCOPE

1.1. This test method covers a procedure for running a repetitive static plate load test on soils in either the compacted or natural state.

1.2. The values stated in inch-pound units are to be regarded as the standard.

2. DEFINITIONS

2.1. *Deflection* - the amount of downward vertical movement of a surface due to the application of a load to the surface

2.2. *Rebound Deflection*- the amount of vertical rebound of a surface that occurs when a load is removed from the surface

2.3. *R*esidual *Deflection*- the difference between original and final elevations of a surface resulting from the applications and removal of one or more loads to and from the surface

3. APPARATUS

Figures 1, 2, and 3 shows the required field test apparatus.

3.1. *Loading Device* - A truck or trailer, a tractor trailer, an anchored frame, a drill rig or other structure loaded with sufficient mass to produce a reaction of at least 10,000 pounds on the surface under the test. NCDOT commonly uses a drill rig. Supporting points, wheels or rear drill rig leveling jacks shall be at least 4 ft. from the edge of the largest diameter plate.

3.2. *Hydraulic Jack Assembly*- A spherical bearing attachment capable of applying and releasing load at a controlled rate. The jack shall have a minimum capacity of 10,000 lbs. If a drill rig is used, it must be equipped with valves that can apply load in a controlled manner. Also, it must have all the accessories such as rods, subs and adaptors required to run the test.

3.3 *Load Cell*- The function of the load cell is to measure applied axial load. It must have a minimum capacity of 12,000 lbs and a maximum capacity of 15,000 lbs. It must have an accuracy of 0.1% of the maximum load capacity (± 15 lbs.). Load cell calibration shall be checked at least once a month using another calibrated load cell or proving ring. Additionally, it shall be checked any time a load cell problem is suspected. Full calibration of load cell is required at least once every 12 months and calibration certificates should be provided to ensure compliance.

3.4. *Bearing Plate*- A set of circular steel plates not less than 1.0 inch in thickness, machined so they can be arranged in pyramid fashion to ensure rigidity and have diameters ranging from 6 to 18 inches. The diameter of adjacent plates in the pyramid arrangement shall not differ by more than 6 inches. NCDOT uses the 18 inch diameter plate as the standard plate size for testing soils.

3.5. *Deflection Beam*- The beam shall be a minimum 2"x2" square aluminum structural tubing with a wall thickness of at least 3/16 " and a minimum length of 6 ft. It shall rest on supports located at least 3 ft. from the edge of the bearing plate or nearest wheel, supporting leg or rear drill rig's leveling jacks.

3.6. *LVDT's*- Two LVDT's capable of recording an accumulated deflection of at least 1.5 inch are required. The LVDT's will be used to record deflections. LVDT's must be calibrated at least once every 12 months and calibration certificates should be provided to ensure compliance.

3.7. *Data Acquisition System*- An analog to digital data acquisition system is required. The overall system should include software to control the test and provide automatic data reduction to minimize chance for errors and maximize production. The data acquisition system must have a minimum of 3 channels and an ability to acquire 1000 data points per channel. It must have the necessary accessories to communicate with a computer.

3.8. *Lap Top Computer*- Required for data processing and analysis.

3.9. *Miscellaneous Tools*- A spirit level for preparation of the surface to be tested and ensuring testing equipment is level and plumb, thermometer, stop watch, etc.

3.10. *Power Supply*- A portable generator or vehicle battery is adequate.

4. PROCEDURE

4.1. Level the area to be tested with Ottawa sand using a straight edge and ensure test surface is level using a 2 ft. long spirit level. Use the least quantity of sand required for uniform bearing. If additional in-situ testing is to be conducted, cover the exposed soil materials to a distance of 6 ft. from the edge of the bearing plate with a tarpaulin or proof paper to prevent moisture loss during the test.

4.2. Seat the 18 inch bearing plate on the leveled surface and verify that it is level. One way to do this is apply a 50 pound load and then check whether the plate is level. If it is not level, remove the load, turn or work the plate back and forth and then apply the 50 pound load and check the level again. Repeat this process until uniformly level seating of the plate is achieved. Center the remaining plates of smaller diameters concentric with and on top of the bearing plate. Center the hydraulic jack or the drill rods on the smallest diameter plate. Place the load cell between the hydraulic jack and the loading device. In the case of drill rigs, the top load cell is attached to a short rod connected to the drill head and the bottom of load cell is attached to a longer rod that directly applies the load to the plate assembly.

4.3. Mount the LVDT's onto the deflection beam. Place the LVDT's so that the stems rest on the bearing plate not more than ¾ inches from the outer plate edge spaced 180 degrees apart. Ensure the deflection beam is level and the LVDT's have sufficient travel length to accommodate a minimum deflection of 1.5 inch. Extreme care must be exercised in order to avoid touching or bumping into the deflection beam while the test is in progress.

4.4. Connect the cables for LVDT's and load cell to the data acquisition system. Also connect the data acquisition system to the lap top Computer. Connect lap top Computer and data acquisition system to the power supply system.

4.5. Confirm all electronic components are working, drill rig is level and load application system is plumb.

4.6. Seating Procedure: Seat the loading system and bearing plate by applying a load of 1,000 pounds. Maintain the seating load for a minimum period of 2 minutes. Record the deflections reading from each LVDT for the 1,000 pound seating load and calculate the average deflection. Do not start the test until the deflection from each LVDT does not change by more than 0.001" per 30 seconds.

4.7. Load Application: Apply load continuously at a rate of 1000 lbs. per 15 seconds until a load of 10,000 lbs. is achieved. Maintain the 10,000 lbs. load for one minute and then start decreasing the load at a rate of 1000 lbs. per minute for the first 1000 pounds (from 10,000 to 9,000 lbs.) and then increase the rate to 1000 lbs. per 15 seconds from 9000 lbs. to 1000 lbs. Maintain the 1000 lbs. load constant for one minute and then repeat the loading sequence for two more cycles. There is no need to maintain the 1000 pound seating load for 1 minute at the end of the third cycle. Observe the data acquisition system throughout to ensure that all the data is being recorded. The test is terminated after the third cycle.

4.8. Additional Information to be recorded:

4.8.1. - List of personnel
4.8.2. - Weather conditions
4.8.3. - Any irregularity in routine procedure
4.8.4. - Any visual conditions observed at the site
4.8.5. - Air and ground temperature
4.8.6. - Any unusual observation made during the test

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5. CALCULATION AND PLOTTING of LOAD DEFLECTION RELATIONSHIPS

5.1. Raw data obtained from the plate load test consists of applied load, deflection and rebound deflection.

5.2. The average deflection or rebound reflection is obtained from the actual deflections measured by both LVDT's. Deflection is designated by the Greek letter δ.

5.3. Applied load data is divided by the plate area to compute applied stress. Applied load includes the dead weight of the plates. Stress is designated by the Greek symbol sigma σ.

5.4. Compression stiffness ($K_{S\text{-}c}$): This is obtained by dividing change in compressive stress ($\Delta\sigma_c$) by the corresponding change in average deflection ($\Delta\delta$).

$$K_{S\text{-}c} = \frac{\Delta\sigma_c}{\Delta\,\delta_c}$$ Equation 1

5.5. Resilient stiffness ($K_{S\text{-}R}$): This is obtained by dividing change in rebound stress by the corresponding change in rebound deflection. ($\Delta\delta r$)

$$K_{S\text{-}R} = \frac{\Delta\sigma_R}{\Delta\delta r} \qquad \text{Equation 2}$$

5.6. Compression Modulus ($E_{S\text{-}C}$): This is computed using one layer elastic equation developed by Ahlvin and Utery based on Boussinesq theory and assuming material is homogeneous, isotropic and semi-infinite elastic.

$$E = \frac{\sigma (1 + \upsilon)\, a}{\delta_c} \left[\frac{z}{a} A + (1 - M) H \right] \qquad \text{Equation 3}$$

Where:

υ = Poisson's ratio (assumed to be 0.3),
a = plate radius,
Z = depth in radii = 0 for our applications,
A = 1.0 for our applications,
H = 2.0 for our applications, and
E, σ, and δ_c are as previously defined.

Equation 3 is reduced to the following for the 18" plate.

$$E = (16.38) \left(\frac{\sigma}{\delta}\right) \qquad \text{Equation 4}$$

Therefore

$$E_{S\text{-}C} = (16.38)(K_{S\text{-}C}) \qquad \text{Equation 5}$$

5.7. Resilient Modulus (E_R): Uses same process as compression modulus.

$$M_{S\text{-}R} = (16.38)(K_{S\text{-}R}) \qquad \text{Equation 6}$$

5.8. Compression Strain ($\varepsilon_{S\text{-}C}$): This is obtained by dividing compressive stress by corresponding compression modulus and then multiplying by 100 to obtain percent strain.

5.9. Resilient Strain ($\varepsilon_{S\text{-}R}$): This is obtained by dividing rebound stress by the corresponding resilient modulus and then multiplying by 100 to obtain percent strain.

5.10. Compressive Stiffness and Modulus values are computed for change in applied stress of approximately 2.5 psi, 5 psi, 10 psi, 15 psi, 20 psi, 25 psi, and 30 psi for each cycle. Resilient Stiffness and Modulus values are computed for a change in applied stress of approximately 5 psi, 10 psi, 15 psi, 20 psi, 25 psi and 30 psi. The data is summarized in a table format as shown below:

PROJECT ID INFORMATION

CYCLE #	COMPRESSION					REBOUND				
	$\Delta\sigma_c$	δ_c	K_{S-C}	E_{S-C}	ε_{S-C} (%)	$\Delta\sigma_R$	δ_R	K_{S-R}	E_{S-R}	ε_{S-R}(%)
1	2.5					5				
1	5					10				
1	10					15				
1	15					20				
1	20					25				
1	25					30				
1	30									
2	2.5					5				
2	5					10				
2	10					15				
2	15					20				
2	20					25				
2	25					30				
2	30									
3	2.5					5				
3	5					10				
3	10					15				
3	15					20				
3	20					25				
3	25					30				
3	30									

5.11. Compression Modulus values for cycle 1, are typically lower than those for cycles 2 and 3, therefore only data for cycles 2 & 3 is included in further analysis.

5.12. Resilient Modulus values for all 3 cycles are generally the same therefore, for subsequent resilient modulus analysis data for all 3 cycles is included.

5.13. Plot Stress vs. average deflection graphs. One graph for all 3 cycles is required.

5.14. Plot arithmetic and log- log graphs of Compressive & Resilient Modulus vs. Stress for cycles 2 & 3 in case of compressive modulus and all 3 cycles for Resilient Modulus.

5.15. Perform a regression analysis of the log-log graphs to obtain regression constants K_1 and K_2 for use in computing modulus at any stress value using the following constitutive models:

$E_{S\text{-}C}$ or $E_{S\text{-}R} = K_1 P_a^{K2}(\sigma/P_a)^{K2}$ for fine grained soils.

$E_{S\text{-}C}$ or $E_{S\text{-}R} = K_1 P_a^{K2}(\acute{\varnothing}/ P_a)^{K2}$ for course grained soils.

Where:

P_a = Atmospheric Pressure
σ = Applied axial stress or deviator stress.
$\acute{\varnothing}$ = Bulk stress = $\sigma_1 + \sigma_2 + \sigma_3$
All other variables as previously defined.

Note: The regression constants are considered good if R^2 is equal to or greater than 0.95.

5.16. If a single value of modulus is needed, NCDOT typically selects modulus values corresponding to an axial stress of 15psi.

5.17 A complete example of data analysis and presentation is summarized in Appendix A.

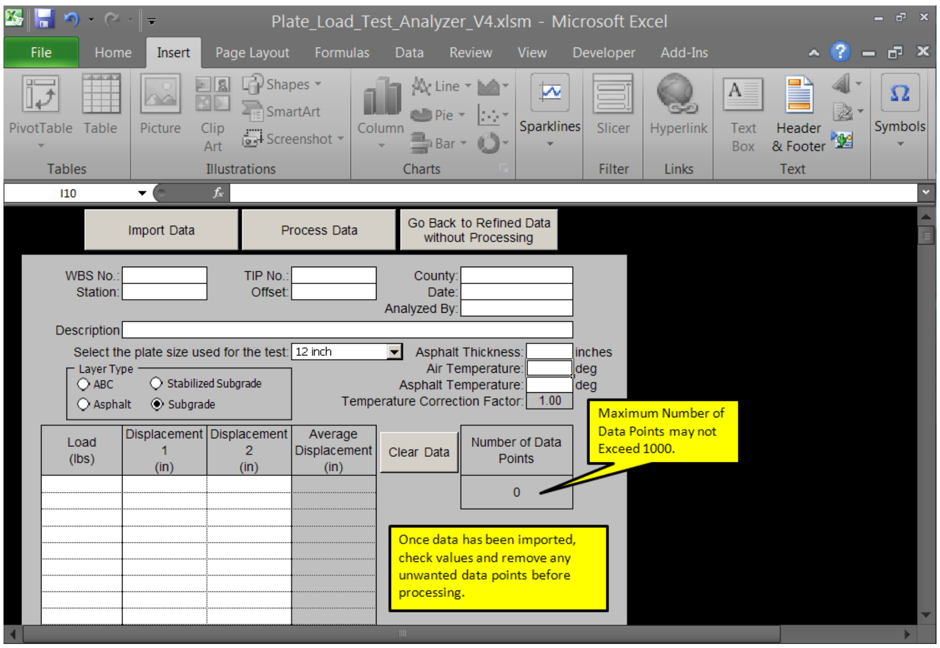
6. PRECISION AND BIAS

6.1 Data for developing precision for a single operator is being gathered and this section will be updated when data collection and analysis is complete.

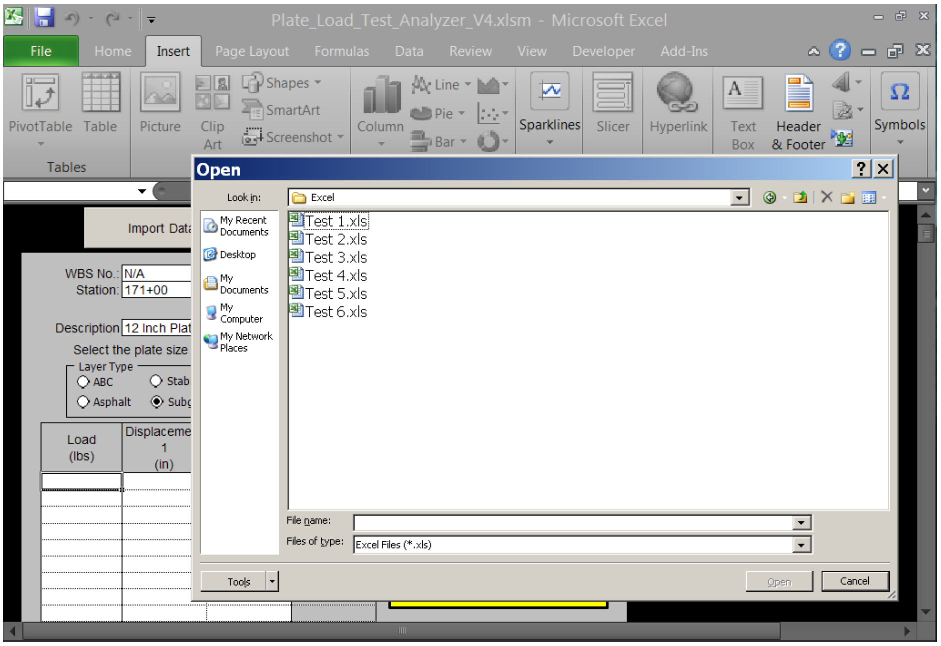
Appendix A:

The following is an example of how to analyze raw test data using the Plate Load Test Analyzer.

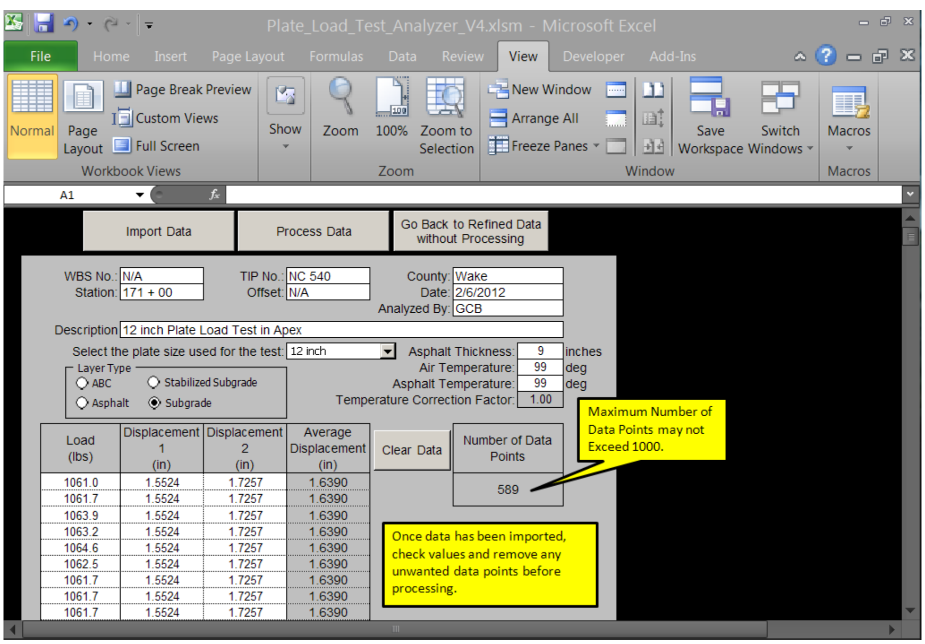
Step 1: Enter the general project information. Select the type of layer using the selection box and select a plate size using the dropdown box. Enter the asphalt thickness and the temperature information.



Step 2: Import the raw test data by clicking on the "Import Data" button. Select the ".xls" file for the desired test and click " Open."

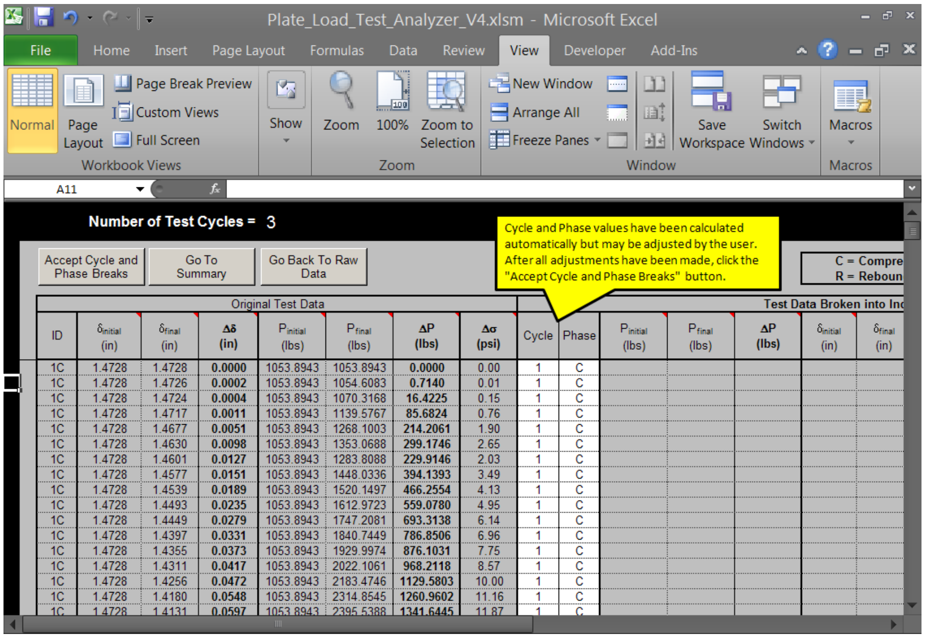


Step 3: Look over the raw test data and remove any incorrect data points. These may be data points at the end of the test where the average deflection or applied axial load are negative numbers. The maximum number of data points must be less than or equal to 1000. Click the "Process Data" button to process the raw data.



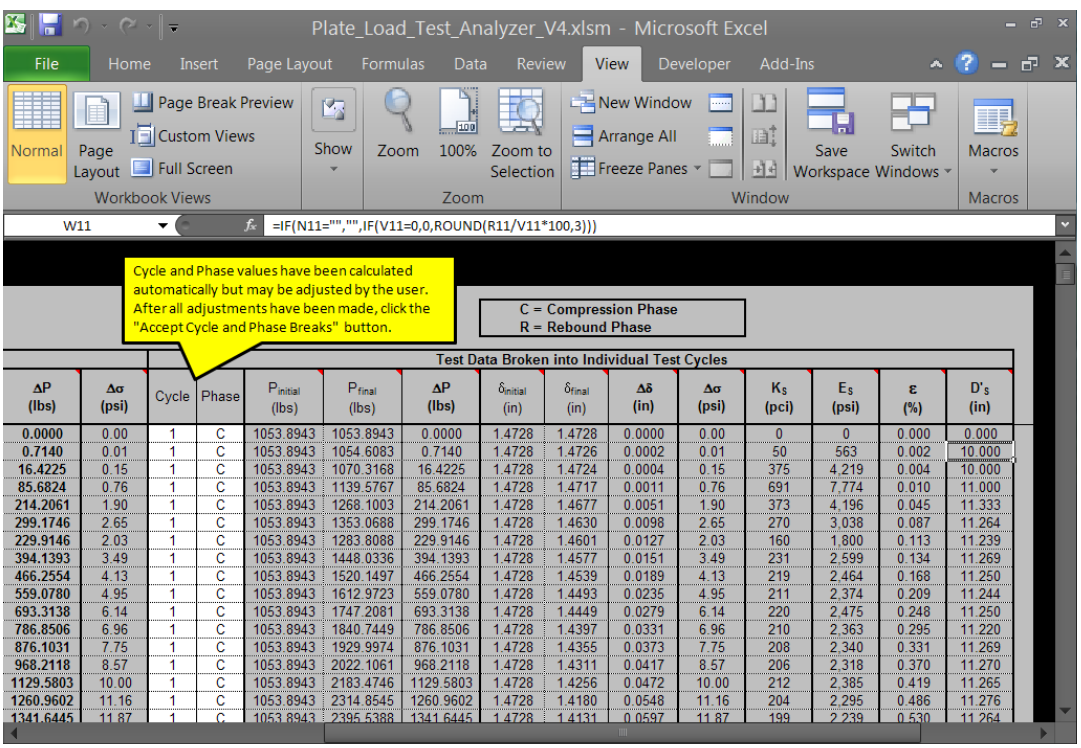
Step 4: The analyzer will break the raw data into test cycles. Each cycle will be broken into a "Compression" phase and a "Rebound" phase. The user can manually adjust the beginning and ending points for these by changing the values in the "Cycle" and Phase"

columns. Once the cycle and phase values are acceptable, click the "Accept Cycle and Phase Breaks" button.



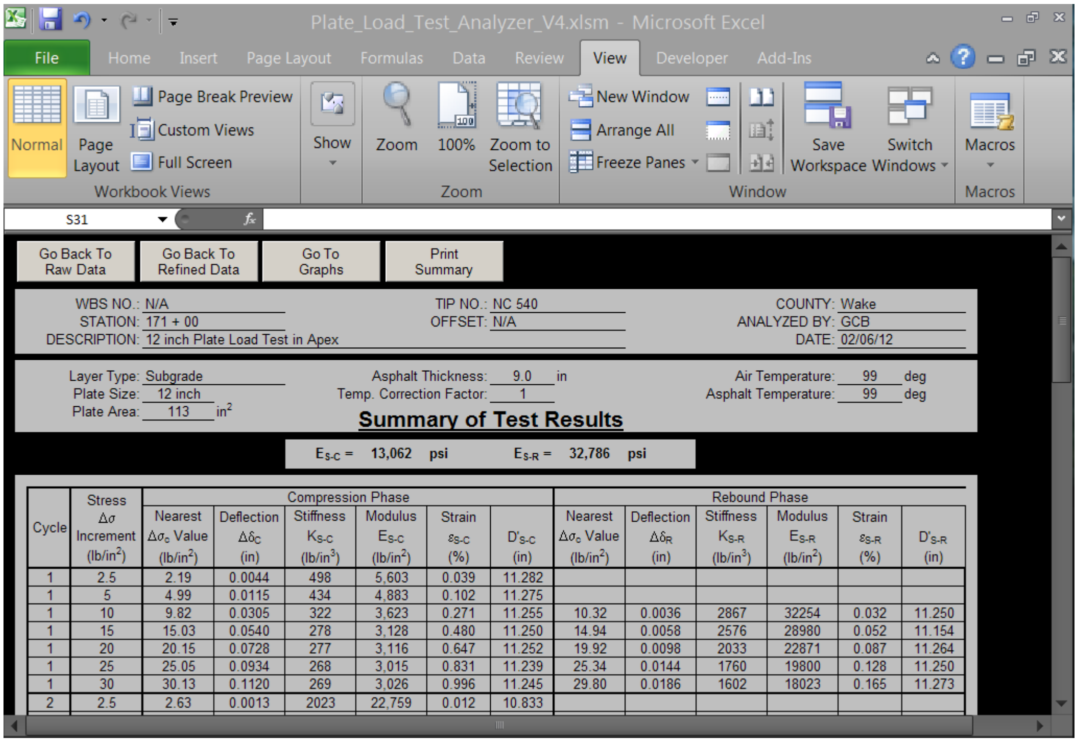
Original Test Data								Test Data Broken into Ind						
ID	$\delta_{initial}$ (in)	δ_{final} (in)	$\Delta\delta$ (in)	$P_{initial}$ (lbs)	P_{final} (lbs)	ΔP (lbs)	$\Delta\sigma$ (psi)	Cycle	Phase	$P_{initial}$ (lbs)	P_{final} (lbs)	ΔP (lbs)	$\delta_{initial}$ (in)	δ_{final} (in)
1C	1.4728	1.4728	0.0000	1053.8943	1053.8943	0.0000	0.00	1	C					
1C	1.4728	1.4726	0.0002	1053.8943	1054.6083	0.7140	0.01	1	C					
1C	1.4728	1.4724	0.0004	1053.8943	1070.3168	16.4225	0.15	1	C					
1C	1.4728	1.4717	0.0011	1053.8943	1139.5767	85.6824	0.76	1	C					
1C	1.4728	1.4677	0.0051	1053.8943	1268.1003	214.2061	1.90	1	C					
1C	1.4728	1.4630	0.0098	1053.8943	1353.0688	299.1746	2.65	1	C					
1C	1.4728	1.4601	0.0127	1053.8943	1283.8088	229.9146	2.03	1	C					
1C	1.4728	1.4577	0.0151	1053.8943	1448.0336	394.1393	3.49	1	C					
1C	1.4728	1.4539	0.0189	1053.8943	1520.1497	466.2554	4.13	1	C					
1C	1.4728	1.4493	0.0235	1053.8943	1612.9723	559.0780	4.95	1	C					
1C	1.4728	1.4449	0.0279	1053.8943	1747.2081	693.3138	6.14	1	C					
1C	1.4728	1.4397	0.0331	1053.8943	1840.7449	786.8506	6.96	1	C					
1C	1.4728	1.4355	0.0373	1053.8943	1929.9974	876.1031	7.75	1	C					
1C	1.4728	1.4311	0.0417	1053.8943	2022.1061	968.2118	8.57	1	C					
1C	1.4728	1.4256	0.0472	1053.8943	2183.4746	1129.5803	10.00	1	C					
1C	1.4728	1.4180	0.0548	1053.8943	2314.8545	1260.9602	11.16	1	C					
1C	1.4728	1.4131	0.0597	1053.8943	2395.5388	1341.6445	11.87	1	C					

The analyzer will calculate parameters for each cycle and phase. Click on the "Go To Summary" button to see a summary of the results.



		Test Data Broken into Individual Test Cycles												
ΔP (lbs)	$\Delta\sigma$ (psi)	Cycle	Phase	$P_{initial}$ (lbs)	P_{final} (lbs)	ΔP (lbs)	$\delta_{initial}$ (in)	δ_{final} (in)	$\Delta\delta$ (in)	$\Delta\sigma$ (psi)	K_S (pci)	E_S (psi)	ε (%)	D'_S (in)
0.0000	0.00	1	C	1053.8943	1053.8943	0.0000	1.4728	1.4728	0.0000	0.00	0	0	0.000	0.000
0.7140	0.01	1	C	1053.8943	1054.6083	0.7140	1.4728	1.4726	0.0002	0.01	50	563	0.002	10.000
16.4225	0.15	1	C	1053.8943	1070.3168	16.4225	1.4728	1.4724	0.0004	0.15	375	4,219	0.004	10.000
85.6824	0.76	1	C	1053.8943	1139.5767	85.6824	1.4728	1.4717	0.0011	0.76	691	7,774	0.010	11.000
214.2061	1.90	1	C	1053.8943	1268.1003	214.2061	1.4728	1.4677	0.0051	1.90	373	4,196	0.045	11.333
299.1746	2.65	1	C	1053.8943	1353.0688	299.1746	1.4728	1.4630	0.0098	2.65	270	3,038	0.087	11.264
229.9146	2.03	1	C	1053.8943	1283.8088	229.9146	1.4728	1.4601	0.0127	2.03	160	1,800	0.113	11.239
394.1393	3.49	1	C	1053.8943	1448.0336	394.1393	1.4728	1.4577	0.0151	3.49	231	2,599	0.134	11.269
466.2554	4.13	1	C	1053.8943	1520.1497	466.2554	1.4728	1.4539	0.0189	4.13	219	2,464	0.168	11.250
559.0780	4.95	1	C	1053.8943	1612.9723	559.0780	1.4728	1.4493	0.0235	4.95	211	2,374	0.209	11.244
693.3138	6.14	1	C	1053.8943	1747.2081	693.3138	1.4728	1.4449	0.0279	6.14	220	2,475	0.248	11.250
786.8506	6.96	1	C	1053.8943	1840.7449	786.8506	1.4728	1.4397	0.0331	6.96	210	2,363	0.295	11.220
876.1031	7.75	1	C	1053.8943	1929.9974	876.1031	1.4728	1.4355	0.0373	7.75	208	2,340	0.331	11.269
968.2118	8.57	1	C	1053.8943	2022.1061	968.2118	1.4728	1.4311	0.0417	8.57	206	2,318	0.370	11.270
1129.5803	10.00	1	C	1053.8943	2183.4746	1129.5803	1.4728	1.4256	0.0472	10.00	212	2,385	0.419	11.265
1260.9602	11.16	1	C	1053.8943	2314.8545	1260.9602	1.4728	1.4180	0.0548	11.16	204	2,295	0.486	11.276
1341.6445	11.87	1	C	1053.8943	2395.5388	1341.6445	1.4728	1.4131	0.0597	11.87	199	2,239	0.530	11.264

Step 5: Print a copy of the summary by clicking the "Print Summary" button. To view the results in a graphical format, click the "Go To Graphs" button.



WBS NO.: N/A
STATION: 171 + 00
DESCRIPTION: 12 inch Plate Load Test in Apex

TIP NO.: NC 540
OFFSET: N/A

COUNTY: Wake
ANALYZED BY: GCB
DATE: 02/06/12

Layer Type: Subgrade
Plate Size: 12 inch
Plate Area: 113 in^2

Asphalt Thickness: 9.0 in
Temp. Correction Factor: 1

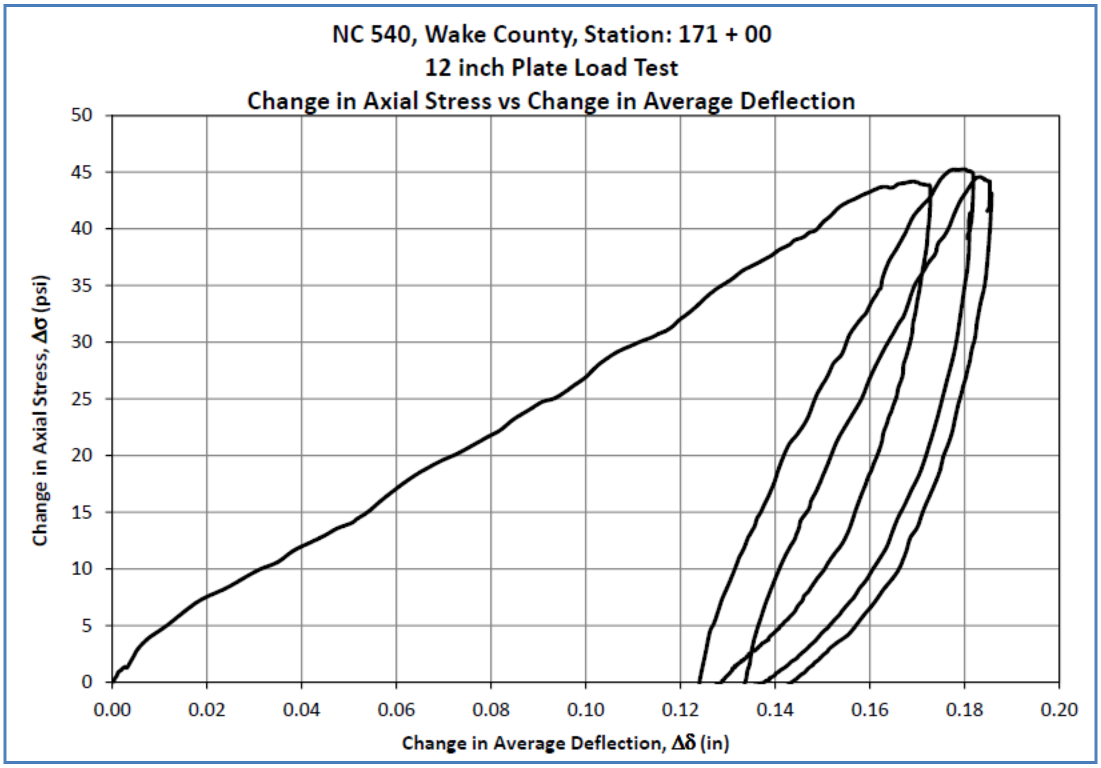
Air Temperature: 99 deg
Asphalt Temperature: 99 deg

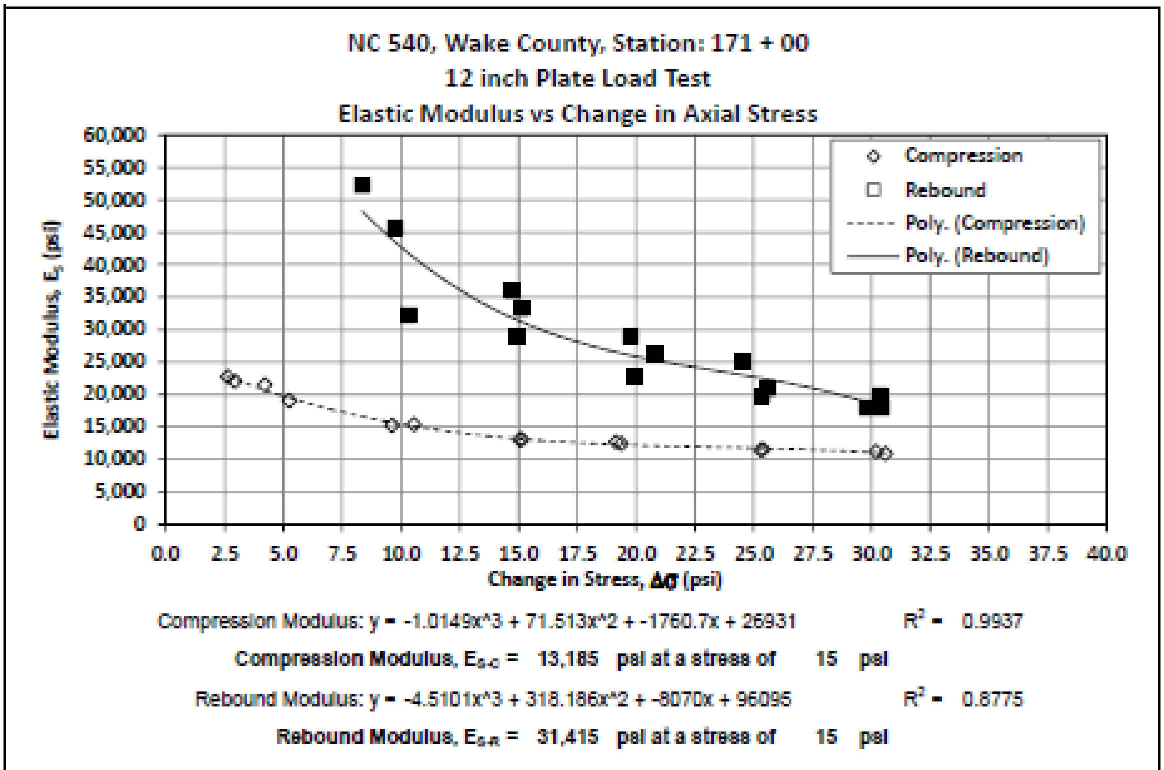
Summary of Test Results

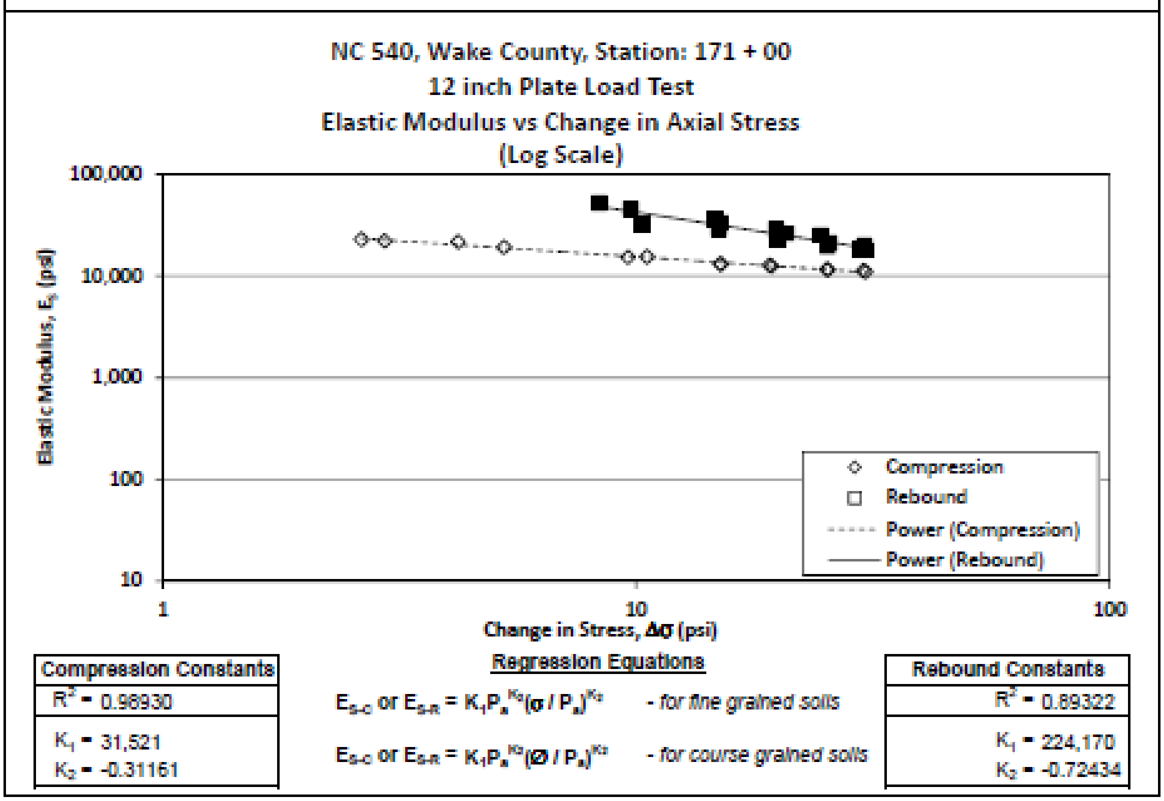
$E_{s\text{-}C}$ = 13,062 psi $E_{s\text{-}R}$ = 32,786 psi

Cycle	Stress $\Delta\sigma$ Increment (lb/in^2)	Compression Phase: Nearest $\Delta\sigma_c$ Value (lb/in^2)	Deflection $\Delta\delta_C$ (in)	Stiffness $K_{s\text{-}C}$ (lb/in^3)	Modulus $E_{s\text{-}C}$ (lb/in^2)	Strain $\varepsilon_{s\text{-}C}$ (%)	$D'_{s\text{-}C}$ (in)	Rebound Phase: Nearest $\Delta\sigma_c$ Value (lb/in^2)	Deflection $\Delta\delta_R$ (in)	Stiffness $K_{s\text{-}R}$ (lb/in^3)	Modulus $E_{s\text{-}R}$ (lb/in^2)	Strain $\varepsilon_{s\text{-}R}$ (%)	$D'_{s\text{-}R}$ (in)
1	2.5	2.19	0.0044	498	5,603	0.039	11.282						
1	5	4.99	0.0115	434	4,883	0.102	11.275						
1	10	9.82	0.0305	322	3,623	0.271	11.255	10.32	0.0036	2867	32254	0.032	11.250
1	15	15.03	0.0540	278	3,128	0.480	11.250	14.94	0.0058	2576	28980	0.052	11.154
1	20	20.15	0.0728	277	3,116	0.647	11.252	19.92	0.0098	2033	22871	0.087	11.264
1	25	25.05	0.0934	268	3,015	0.831	11.239	25.34	0.0144	1760	19800	0.128	11.250
1	30	30.13	0.1120	269	3,026	0.996	11.245	29.80	0.0186	1602	18023	0.165	11.273
2	2.5	2.63	0.0013	2023	22,759	0.012	10.833						
2	5	5.26	0.0031	1697	19,091	0.028	11.071						
2	10	9.63	0.0071	1356	15,255	0.063	11.270	8.36	0.0018	4644	52245	0.016	11.250
2	15	15.05	0.0130	1158	13,028	0.116	11.207	15.11	0.0051	2963	33334	0.045	11.333
2	20	19.16	0.0170	1127	12,679	0.151	11.258	20.81	0.0089	2338	26303	0.079	11.266
2	25	25.41	0.0248	1025	11,531	0.22	11.273	25.59	0.0137	1868	21015	0.122	11.230
2	30	30.6	0.0316	968	10,890	0.281	11.246	30.44	0.0191	1594	17933	0.17	11.235
3	2.5	2.94	0.0015	1960	22,050	0.013	11.538						
3	5	4.21	0.0022	1914	21,533	0.02	11.000						
3	10	10.55	0.0077	1370	15,413	0.068	11.324	9.74	0.0024	4058	45653	0.021	11.429
3	15	15.13	0.0130	1164	13,095	0.116	11.207	14.74	0.0046	3204	36045	0.041	11.220
3	20	19.37	0.0175	1107	12,454	0.156	11.218	19.78	0.0077	2569	28901	0.068	11.324
3	25	25.29	0.0248	1020	11,475	0.22	11.273	24.54	0.011	2231	25099	0.098	11.224
3	30	30.2	0.0303	997	11,216	0.269	11.264	30.37	0.0172	1766	19868	0.153	11.242

<u>Step 6</u>: Graphs can be printed by clicking on the “Print” button located in the top right corner of each graph.







The Log-Log plot above is used to calculate parameters K_1 and K_2 for the regression line that can be used to calculate the modulus at any stress value. The regression line is considered to be a good model when the R^2 values are greater than or equal to 0.95.